6.3 Emergency Core Cooling System

The safety injection system (SIS) provides emergency core cooling for the U.S. EPR. Four supply and return trains comprise the system, one for each of the reactor coolant system (RCS) loops. Individually, each of these trains can supply the required core cooling. The four supply trains, which serve the safety injection function, charge through parallel paths from a low head safety injection (LHSI) pump, a medium head safety injection (MHSI) pump, and an accumulator in each train. The injection pumps draw water from the in-containment refueling water storage tank (IRWST) for their emergency function. The IRWST also provides gravity-driven coolant flow through the non-safety-related severe accident heat removal system (SAHRS) flooding lines to quench molten corium in the core spreading area during severe accidents.

The MHSI pumps and the accumulators inject directly into the cold legs. The LHSI pumps inject through the LHSI heat exchangers (HX) to the cold legs. Closed loop cooling via the LHSI pump (in residual heat removal mode) for post-accident heat removal is also available by aligning the suction to the RCS hot legs. The LHSI system may be realigned during accident recovery for hot-leg injection to prevent boron precipitation and mitigate steaming from the break. During severe accidents, an operator action is required when the core outlet temperature reaches 1200°F to open the normally closed, de-energized, SAHRS passive flooding line motor-operated isolation valves upstream of the normally closed passive flooding devices to initiate coolant flow to the core spreading area. This arrangement protects the IRWST inventory against a single failure that could result in inadequate IRWST level to maintain sufficient ECCS pump NPSH. The SAHRS is also capable of providing support for mitigation of a beyond design basis event.

The SAHRS passive flooding line motor-operated isolation valves are powered by the Class 1E electrical distribution system and can receive power from offsite power sources, emergency diesel generator or the SBO diesel generator. In addition, safety-related motor-operated isolation valves are backed by battery power (12UPS) during a severe accident with a loss of offsite power and emergency diesel generators.

The residual heat removal (RHR) function of the safety injection system/residual heat removal system (SIS/RHRS) for normal shutdown cooling of the reactor is described in Section 5.4.7. The SAHRS passive flooding lines and their function are described in Tier 2, Section 19.2.

6.3.1 Design Bases

The SIS limits fuel assembly damage during core flooding and emergency core cooling following a loss of coolant accident (LOCA). The SIS removes post-accident decay heat from the RCS and provides post-accident containment cooling via the LHSI HXs. The system consists of four independent and separated trains, each housed and protected in its own seismically qualified Safeguard Building (SB), as further described in Section 6.3.2. This separation and independence provides protection from physical damage due to natural phenomena and hazards and allows fulfillment of the system safety function in the event of a single failure.

Following postulated LOCAs, the SIS maintains fuel cladding temperature, cladding oxidation, hydrogen generation, core geometry, and long-term core temperature within the limits specified in 10 CFR 50.46. SIS actuation provides protection for the following postulated transients, accidents, and operational events:

- Main steam line break (MSLB) - Following a small or large MSLB, the MHSI trains provide RCS boration and coolant inventory control during cooldown.
- Steam generator tube rupture (SGTR) - Following an SGTR, the MHSI trains inject borated water to provide a sufficient coolant inventory.
- Small-break LOCA (SBLOCA), break size less than or equal to 0.5 ft^2 - The SIS, in conjunction with automatic secondary-side partial cooldown, provides borated coolant injection, which limits RCS draining and keeps the core covered and cooled throughout the event. The system provides this function even if there is a loss of a train due to the most limiting single failure coincident with one train unavailable because of maintenance. Further evaluation of SIS performance for this limiting event is presented in Section 6.3.3.
- Large-break LOCA (LBLOCA), break size greater than 0.5 ft^2 up to a complete rupture of an RCS hot or cold leg - To avoid exceeding the limits of 10 CFR 50.46, the SIS provides sufficient core cooling even if there is a loss of a train, due to the most limiting single failure, coincident with one train being unavailable due to maintenance. Further evaluation of SIS performance for this limiting event is presented in Section 6.3.3.
- Inadvertent opening of a pressurizer safety relief valve (PSRV) - The MHSI pumps provide RCS makeup in the event of inadvertent opening of a PSRV.
- RCS loop level decrease during shutdown or midloop operation - The MHSI pumps provide RCS makeup in the event of spurious draining of the RCS or SBLOCA during shutdown cooling operations. To compensate for the reduced pressure and makeup flow requirement for this operational condition, the large MHSI minimum flow line opens prior to injection to reduce the MHSI injection head. RCS pressure remains below approximately 580 psia during this event.

The SIS and its support and ancillary systems are designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Section 3.2 identifies component classifications (GDC 1, 10 CFR 50.55a(a)(1)). Appropriate to its reactor core cooling function, the SIS is:

- Designed to codes consistent with the quality group classification assigned by RG 1.26.

- Protected from the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, and external missiles, and designed to function following such events (GDC 2).
- Designed to the Seismic Category I designation assigned by RG 1.29 so that it remains functional after a safe shutdown earthquake (SSE) (GDC 2).
- Designed to remain functional following the postulated hazards of fire and explosion, internal missiles, pipe whipping, and discharging fluids (GDC 3 and GDC 4).
- Not shared among nuclear power units (GDC 5).
- Provided with both an onsite and an offsite electric power system, each of which can alone power the SIS to its full capacity (GDC 17).
- Capable, in combination with the extra borating system (EBS), of adding sufficient neutron poison to reliably control reactivity changes and maintain core cooling under postulated accident conditions, with an appropriate margin for stuck control rods (GDC 27).
- Designed to remain functional in the event of a single active component failure coincident with the loss of either the onsite or offsite power source (GDC 35).
- Designed to permit appropriate periodic inspection of important components to verify the integrity and capability of the system (GDC 36, GDC 39).
- Designed to permit appropriate periodic pressure and functional testing to confirm:
  - The structural and leak tight integrity of its components.
  - The operability and performance of its active components.
  - The operability of the system as a whole. This testing is performed under conditions as close to design as practical for the full operational sequence of the system, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources, and the operation of the associated cooling water system (GDC 37, GDC 40).
- Designed, through the features built into the in-containment refueling water storage tank system (IRWSTS), to reduce the containment pressure and temperature following a loss of coolant accident (LOCA) and maintain them at acceptably low levels (GDC 38), and to provide long term post-LOCA core cooling requirements as required in 10 CFR 50.46(b)(5).
- Designed to perform under anticipated normal, testing, and design basis accident environmental conditions in compliance with 10 CFR 50.49.

- Supplied by highly reliable, Class 1E, and diverse power and control systems in conformance with RG 1.32. Class 1E power supply for the U.S. EPR is addressed in Chapter 8.
- Supplied by a highly reliable water source (the IRWST) for long-term recirculation cooling following a LOCA, with adequate protection against loss of net positive suction head (NPSH) due to debris entrainment, in conformance with RG 1.82.
- Designed with the capability for leakage detection and control to minimize the leakage from those portions of the SIS outside of the containment that may contain radioactive material following an accident (10 CFR 50.34(f)(2)(xxvi)).

Positive indication is provided in the control room of flow in the discharge pipe from the RCS safety and relief valves (10 CFR 50.34(f)(2)(xi)) as described in Section 5.2.2. Reactor vessel instrumentation described in Section 7.5.2.1 displays an unambiguous, easy-to-interpret indication of inadequate core cooling (10 CFR 50.34(f)(2)(xviii)).

The SIS design and analysis incorporates resolution of the relevant USIs, and medium- and high-priority GSIs, specified in NUREG-0933 (Reference 1). Table 1.9-3—U.S. EPR Conformance with TMI Requirements (10 CFR 50.34(f)) and Generic Issues (NUREG-0933) identifies where each relevant issue is addressed.

The SIS design incorporates operating experience insights from the following generic letters and bulletins:

- GL 80-014 (Reference 2) addresses LWR primary coolant system pressure isolation valves, specifically the mitigation of interfacing systems LOCA. The SIS design features addressing intersystem LOCA are described in Section 5.4.7.
- GL 80-035 (Reference 3) addresses the effect of a DC power supply failure on SIS performance. The four-train SIS design, with independent emergency power supplied to each train, addresses this issue by providing sufficient redundancy to perform its functions even with the unavailability of an entire train as described in Section 6.3.2.5.
- GL 81-021 (Reference 4) addresses natural circulation cooldown. This issue is addressed in Sections 10.4.9.3 and 15.0.4.1.
- GL 85-16 (Reference 5) addresses the effects of high boron concentrations. The borated water from the IRWST, where the SIS pumps take suction, is not easily susceptible to precipitation due to its relatively low boron concentration. The extra borating system injects concentrated boric acid solution when required to maintain reactivity margin for plant shutdown. The EBS is designed to prevent boric acid crystallization as described in Section 6.8.
- GL 86-07 (Reference 6) addresses the effects and prevention of water hammer. Refer to Section 5.4.7 for discussion of provisions for the prevention of water hammer in the SIS piping.

- GL 89-10 (Reference 7) addresses safety-related motor-operated valve testing and surveillance. This issue is addressed in Section 3.9.6.
- GL 91-07 (Reference 8) addresses reactor coolant pump (RCP) seal failure and station blackout. Refer to Section 5.4.1 for discussion of provisions for RCP seal failure and station blackout.
- GL 98-04 (Reference 9) addresses the potential for degradation of emergency core cooling and the containment spray systems after a LOCA due to construction and protective coating deficiencies and the entrainment of debris in recirculating reactor coolant. This issue is described in Section 6.3.2.5.
- GL 2004-02 (Reference 18) addresses the potential susceptibility of pressurized water reactor recirculation sump screens to debris blockage during design basis accidents and the potential for additional adverse effects due to debris blockage of flow paths necessary for recirculation and containment drainage. This issue is addressed in Section 6.3.2.5.
- BL 80-18 (Reference 10) addresses the maintenance of adequate minimum flow through centrifugal charging pumps following secondary side high energy line ruptures. The SIS pumps include minimum flow lines that provide adequate recirculation to prevent overheating of the pumps as described in Section 6.3.2.2.
- BL 86-03 (Reference 11) addresses potential failure of multiple ECCS pumps due to single failure of air-operated valves (AOV) in minimum flow recirculation lines. AOVs are not used in the SIS.
- BL 88-04 (Reference 12) addresses the potential for the loss of pump function due to deficiencies in the design of minimum flow lines. The SIS design addresses this issue by incorporating separate minimum flow lines that are not shared among the SIS pumps as described in Section 6.3.2.5.
- BL 93-02 (Reference 13) addresses debris plugging of emergency core cooling suction strainers. This issue is addressed in Section 6.3.2.5.
- BL 01-01 (Reference 14) addresses circumferential cracking of reactor pressure vessel head penetration nozzles. This issue is addressed in Section 5.2.3.
- BL 02-01 (Reference 15) addresses reactor vessel head degradation and reactor coolant pressure boundary integrity. This issue is addressed in Section 5.2.3.

The discharge heads for the SIS accumulators and discharge heads and delivery flowrates for the LHSI system and the MHSI system are listed in Table 6.3-1—Accumulators Design and Operating Parameters, Table 6.3-2—Low Head Safety Injection Pumps Design and Operating Parameters, and Table 6.3-3—Medium Head Safety Injection Pumps Design and Operating Parameters. The SIS provides core cooling capability for a wide spectrum of LOCAs, considering the hydraulic flow resistance of the SIS piping and valves and the available NPSH. The volume of the IRWST, as listed in Table 6.3-4—LHSI Heat Exchanger Design and Operating

Parameters, provides sufficient borated water for long-term core cooling. In addition, the boron concentration in the IRWST, in combination with the EBS, provides negative reactivity to keep the core subcritical.

6.3.2 System Design

6.3.2.1 Schematic Piping and Instrumentation Diagrams

The SIS consists of four independent trains, designated Trains 1, 2, 3, and 4, one supplying each reactor coolant loop. The four trains are separated into four safety divisions and are functionally identical, as shown in Figure 6.3-1—Safety Injection System Overview and Figure 6.3-2—Safety Injection / Residual Heat Removal System Train (Typical). The IRWST arrangement is shown in Figure 6.3-3—IRWST Layout.

Each SIS train has separate MHSI and LHSI pump trains and an accumulator injection train. The MHSI and LHSI pump trains share an isolable suction line from the IRWST. This three-way valve lines up the IRWST to both the MHSI and LHSI pump suctions when in the open position. The LHSI pump train includes an HX and a suction line from the RCS hot leg for residual heat removal, which may be re-aligned for LHSI hot-leg injection. The discharge lines for all three MHSI, LHSI, and accumulator injection trains branch together to share an injection nozzle on their associated RCS cold leg. Cross-connects between Trains 1 and 2 and between Trains 3 and 4, which are normally isolated by two motor-operated valves in series to maintain train separation, allow individual trains to be removed from service for maintenance. Each cross-connect provides an alternate injection path for the train that remains in service. This configuration mitigates the effect of degraded safety injection due to steam entrainment during a LOCA, when the only available LHSI connection (considering one is unavailable due to single failure, another out for maintenance, and another train feeds the broken loop) is located adjacent to the broken leg. During such maintenance activities, the motor-operated valves for both cross-connects are secured open (breakers racked out) for protection against active single failures, as described in Section 6.3.2.5.

The component cooling water system (CCWS) is the cooling medium for the LHSI HXs (all four trains), the MHSI pump motor coolers (all four trains), and the LHSI pump motor and seal coolers for Trains 2 and 3. The safety chilled water system (SCWS) is the cooling medium for the LHSI pump motor and seal coolers for Trains 1 and 4. The essential service water system (ESWS) serves as the final cooling medium, rejecting the heat transferred from the CCWS to the ultimate heat sink.

The four SIS trains are powered, respectively, by electrical divisions 1 through 4. Each electrical division is a separate and independent power supply housed and protected in its own SB. Each electrical division is also supplied by its assigned emergency diesel generator in the event of a loss of offsite power (LOOP). Chapter 8 provides detailed information on the U.S. EPR electrical system.

6.3.2.2 Equipment and Component Descriptions

6.3.2.2.1 System Overview

Each MHSI train consists of a pump, an isolable supply branch from the shared IRWST suction line, and a discharge line that tees into its respective cold-leg LHSI injection line just upstream of the inboard LHSI-to-RCS isolation check valve. A line tees off of the injection line upstream of the inboard MHSI-to-LHSI injection isolation valve and leads back to the IRWST. This line branches into two flow lines; the smaller one for pump minimum flow protection and the larger one for reducing the MHSI discharge head. A line for filling the accumulator tees off of the smallest of these branch lines upstream of its maintenance isolation valve. A control valve, located between the tee to the mini-flow branch lines and the inboard MHSI-to-LHSI injection isolation valve, allows for manual throttling of the MHSI flow, if so required, during long term post-accident management.

Each accumulator injection train has one accumulator whose isolable injection line tees into its respective cold-leg LHSI injection line just upstream of the inboard LHSI-to-RCS isolation check valve.

The LHSI train consists of an LHSI pump, LHSI HX, LHSI HX bypass line with flow control valve, shared suction line from the IRWST with a motor-operated isolation valve, LHSI HX discharge line with temperature control valve, RCS hot-leg suction line, cross-connects between pairs of trains, and various isolation and realignment valves as required to support operation, maintenance, shutdown, or accident mitigation. A mini-flow and test line tees off of the cold-leg injection line upstream of the outboard LHSI-to-RCS isolation check valve. A control valve, located between the tee to the mini-flow line and the outboard LHSI-to-RCS isolation check valve, allows for manual throttling of the LHSI flow, if so required, during long term post-accident management.

A non-safety related pump installed in parallel with the Train 1 MHSI pump supports non-safety core cooling in Mode 6 during an extended loss of AC power (ELAP) event. Further description of the primary coolant injection pump and design is in Technical Report ANP-10329 (Reference 21).

The SIS piping is protected from overpressure events by safety relief valves installed at locations most susceptible to such events. The design overpressure transient is the spurious startup of an MHSI pump with the large mini-flow line isolated. The set-points and capacities for these safety relief valves limit the protected system to 110 percent of its design pressure.

Detection and monitoring of SIS leakage within the Reactor Building (RB) is provided by the reactor coolant pressure boundary (RCPB) leakage detection systems described in Section 5.2.5. Leakage from the SIS in the SBs is detected and monitored by operating procedures and programs. Each SB has sump level indication to detect SIS/ RHRS leakage.

The postulated accident sequences and analyses, including equipment actuation and response times, and design requirements for SIS delivery lag times, are described in Section 15.6.5.

6.3.2.2.2 System Components

Accumulators

Each accumulator is an austenitic stainless steel tank with a total volume of approximately 1950 ft^3 and is filled with approximately 1250–1400 ft^3 (approximately 10,000 gallons) of borated water and approximately 550–700 ft^3 of pressurized nitrogen. Nominal operating pressure is approximately 665 psig. The accumulators are designed so that the nitrogen pressure after their injection is lower than the LHSI discharge pressure. Thus, they do not inject nitrogen into the RCS prior to commencement of LHSI injection, even in the unlikely event of the loss of MHSI pumps. The relevant accumulator design and performance data are presented in Table 6.3-1.

Pumps

The LHSI and MHSI pumps are horizontally mounted, centrifugal pumps with single mechanical seals. Their motors are water cooled by the CCWS, with the exception of the LHSI pumps for Trains 1 and 4, which are cooled by the SCWS. Nominal flowrate for the LHSI pump is approximately 2200 gpm at 480 ft of total developed head (TDH), and for the MHSI pump it is approximately 600 gpm at 2260 ft of TDH. The relevant LHSI and MHSI pump design and performance data are presented in Tables 6.3-2 and 6.3-3, respectively.

The primary coolant injection pump is a horizontally mounted, centrifugal pump with mechanical seals. The pump motor is rated for high temperature. Nominal flowrate for the pump is approximately 330 gpm at 150 ft of total developed head (TDH).

Heat Exchangers

The LHSI HXs are U-tube type, horizontally mounted, with reactor coolant flow through the austenitic stainless steel tubes and CCWS flow through the ferritic shell side. The relevant HX design and performance data are presented in Table 6.3-4—LHSI Heat Exchanger Design and Operating Parameters. Conservative fouling factors are incorporated into the performance evaluation of the LHSI HXs.

Piping, Fittings and Valves

The pipes, valves, and fittings of the SIS are austenitic stainless steel. Their design and performance ratings are commensurate with their expected service conditions. The relevant piping, valves, and fittings design data are presented on Figure 6.3-2—Safety Injection / Residual Heat Removal System Train (Typical).

In-Containment Refueling Water Storage Tank

The IRWST is an open pool within a partly immersed building structure. It is located at the bottom of the containment between the reactor pit and the secondary shield wall, below the level of the heavy floor which supports the primary components. It is connected to various safety and non-safety systems and serves as a water source, heat sink, and return reservoir.

The IRWST supplies borated water to the SIS, the severe accident heat removal system (SAHRS), and the chemical and volume control system (CVCS). It also supplies the fuel pool cooling system (FPCS) via the CVCS suction line. The IRWST provides the necessary inventory of borated water for design basis events. It contains a minimum 66,886 ft^3 of borated water which is monitored for its level, temperature, and homogeneous boron concentration. The water is used for both refueling and SIS operations and provides:

- Sufficient water during plant shutdown to fill the reactor cavity, the internal storage pool, the RB transfer pool, and the RCS.
- Sufficient water depth (static pressure head) to the suction of the SIS, SAHRS, and CVCS pumps during normal and accident conditions (per RG 1.1).
- A heat sink and water inventory for flooding the core melt in the spreading area during a beyond design basis event (severe accident).

The walls of the IRWST are lined with an austenitic stainless steel liner covering the immersed region of the building structure. The liner prevents leaks and the interaction of the boric acid with the concrete structure. Leaks that occur are collected, monitored, and quantified by the nuclear island drain and vent system (NIDVS).

The IRWST is provided with the following three filtering stages for the borated water return path to its integral sumps as shown in Figure 6.3-4—SIS Sump Debris Entrainment Prevention Features:

- The trash racks and the weirs above the heavy floor openings to the IRWST are considered components of the IRWST. After a LOCA, the flow of coolant out of the RCS back to the IRWST passes through four openings in the heavy floor. The trash racks prevent large debris from entering the IRWST, while the weirs provide a barrier that retains sediment and debris on the heavy floor.

- Retaining baskets in the IRWST below each heavy floor opening trap debris transported by the flow past the trash racks and weirs. The retaining baskets also filter flow from the annular space in containment to the IRWST. The openings in the retaining baskets provide efficient retention of fiber and particulate debris. A gap between the top of the baskets and the heavy floor provides a flow path if the retaining basket is full or clogged. Gutters are installed to provide atmospheric separation between the RCS equipment space and the annular space during normal plant operation. During certain LOCA events, flow between each retaining basket and the annular space is permitted by IRWST wall penetrations and the gutters.
- The SIS and SAHRS strainers are arranged above each respective SIS and SAHRS sump. These strainers are designed as large cages with inclined sieves to facilitate debris detachment during backflushing. The opening size of the sieves limits the passage of debris during SIS and SAHRS recirculation flow to avoid pump malfunction and clogging of the smallest restriction in the core. The CVCS sump is also provided with a suction strainer.

The large dispersion area within the IRWST results in low flow velocity and promotes settling of fine debris that passes through the retaining baskets. The orientation of the various IRWST sumps is shown on the sump level plan view on Figure 6.3-5—IRWST Sump Level Plan View. The orientation of the trash racks and weirs is shown on the heavy floor plan view on Figure 6.3-6—IRWST Heavy Floor Level Plan View.

The IRWST sump screen flow performance was evaluated to verify that adequate long-term core cooling remains available in spite of impairment by accident-generated debris as well as debris in containment prior to the accident. The strainer design basis head loss is 2.18 psi at 104°F. The conservative estimate of total debris used for the evaluation, and an estimate of total debris in the containment of the U. S. EPR, is presented in Table 6.3-5. The increased use of reflective metal insulation (RMI), which is not subject to transport to the SIS sumps, in the U. S. EPR design in place of most or all of the fibrous or micro-porous insulation assumed in the evaluation further reduces the potential for post-accident blockage of the sumps.

The features of the IRWST screen design address the issues of GSI-191, as further described in Section 6.3.2.5. Technical Report ANP-10293, "U.S. EPR Design Features to Address GSI-191" (Reference 19) provides additional description of the U.S. EPR design features that limit the impact of post-accident debris accumulation on SIS performance, summarizes the performance evaluations and component test program, and compares the design to the regulatory positions of RG 1.82 and the information requested in GL 2004-02.

Performance of the strainers is enhanced by cleanliness programs that limit debris in the containment. A COL applicant that references the U.S. EPR design certification will describe the containment cleanliness program which limits debris within containment. This program consists of the following elements:

- Controls of permanent and temporary modifications so that changes to analytical inputs and assumptions confirm that the ECCS remains in compliance with 10 CFR 50.46, related regulatory requirements, and is consistent with guidance in RG 1.82 and GL 2004-02.
- Controls for foreign material exclusion to limit the introduction of foreign material and debris sources into containment.
- Controls to assess and manage maintenance activities, including associated temporary changes, to confirm that ECCS function is not reduced by associated changes in analytical inputs or assumptions, or other activities that could introduce debris or potential debris sources into containment.
- Controls on the introduction of coating materials into containment and to address deficiencies of coating materials used in containment.
- [*Latent debris will be limited to 150 pounds (10.2 lbs of fiber and 139.8 lbs of particulate) and 100 ft^2.*]* These latent debris limits derive from U.S. EPR sump strainer and fuel assembly testing that demonstrates adequate long term core cooling under debris-laden coolant conditions.

Coolant pH adjustment baskets containing granulated trisodium phosphate dodecahydrate (TSP-C) are strategically placed in the inlet flow path to the IRWST within the boundary perimeter of the weirs at the four heavy floor openings of the RB. Flow through the baskets dissolves the TSP-C into the coolant that returns to the IRWST to passively neutralize entrained acids and maintain the alkalinity of the coolant. The pH of the recirculated coolant is maintained above 7.0. The control of pH in the recirculated coolant reduces the potential for stress-corrosion cracking of the austenitic stainless steel components, limits the generation of hydrogen attributable to corrosion of containment metals, and minimizes the re-evolution of iodine in post-LOCA containment solution, maintaining the radioiodine in solution to reduce radioactive releases to the environment. The minimum amount of granulated TSP-C for this pH control is 12,200 lb_m. Section 15.0.3.12 provides an evaluation of post-accident water chemistry control.

The IRWST is connected to the molten core spreading area by pipes that are closed during normal operation and accident conditions. If a severe accident occurs, operator action to manually open the normally-closed, de-energized motor-operated isolation valves in the passive flooding lines is required when core outlet temperature reaches 1,200°F. When molten material reaches the spreading area, an actuation device melts, flooding valves open, and IRWST water flows into the spreading area to support the operation of the SAHRS. The IRWST is located at a higher elevation than the core spreading area to provide gravity flooding of the spreading area with the IRWST water inventory. The core spreading area and the SAHRS are described in Section 19.2.3.3.

The debris interceptor components, including trash racks, retention baskets and ECCS strainers, are designed and analyzed per the provisions of ANSI/AISC N690-1994, "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities," including Supplement 2 (S2). The structural qualification of the debris interceptors includes an evaluation of the structural integrity of the supports and anchorages as it relates to the abilities of the trash rack, retention baskets and ECCS strainers to perform their intended function.

The structural design details and structural evaluation of the debris interceptor components, including the anchorages of the components to the walls or the floor and the attachments of the screens, will be provided in a structural evaluation and stress margin report.

The following industry codes and standards are used for the structural qualification of the debris interceptor components.

1. Design Properties of Materials: ASME Boiler & Pressure Vessel Code, Section II, Part D, 2004 edition.
2. Steel Analysis: ANSI/AISC N690-1994,"Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities," including Supplement No. 2.
3. Concrete Anchorages: ACI 349-01/349R-01, "Code Requirements for Nuclear Safety Related Concrete Structures and Commentary."
4. Damping Values: NRC Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," Revision 1, March 2007.

The debris interceptor components such as IRWST Retaining Baskets, trash racks, TSP Baskets and Sump Strainers are categorized as Seismic Category I Mechanical components in U.S. EPR FSAR, Tier 1, Table 2.2.2-1. These components are covered by ITAAC item 3.3 in U.S. EPR FSAR, Tier 1, Table 2.2.2-3.

6.3.2.3 Applicable Codes and Classifications

The SIS design complies with applicable industry codes and standards, and regulatory requirements, commensurate with the appropriate safety function for each of the individual components. Table 3.2.2-1 provides the seismic and other design classifications of the components in the SIS. Sections 3.9, 3.10, 3.11, 7.3, and 8.1.4 further address these requirements and their implementation for the U.S. EPR.

6.3.2.4 Material Specifications and Compatibility

Material selection for the SIS is based on the expected service conditions for the various components, the design life of the unit, and the materials strength and service requirements as further described in Section 3.9.3. SIS components that transport or come into contact with borated water, which are the majority of the pressure retaining, fluid bearing components, are constructed of austenitic stainless steel. The specific materials of construction for the SIS and their compatibility with system fluids are described in Section 6.1.1.

6.3.2.5 System Reliability

The instrumentation and controls (I&C) that initiate the SIS and are used to manage its operation are separated. They are independently powered from the same normal and emergency sources that power the associated motive equipment of the train. The process variables for the I&C, such as RCS pressure and pressurizer level, derive their input from independent sources. The design of the SIS I&C, including its quality, redundancy, and protection against the effects of single failure, is presented in Section 7.3.

The SIS trains meet Seismic Category I criteria for earthquake protection. Each of the four SIS trains is housed in a separate Seismic Category I structure. The buildings also protect the SIS against damage from other natural phenomena, such as floods, severe weather, and external hazards such as missiles. The design of the SBs is described in Section 3.8.4.

The SIS design allows online testing of the individual trains and components to assess their operational status and availability. The accessibility incorporated into the design allows complete testing and inservice inspection of critical components when plant conditions allow, such as during outages. Preoperational testing of the SIS verifies that the as-designed and as-constructed system fulfills its functional requirements. Periodic inservice testing confirms the continuing capability of the system. Testing and inspection activities for the SIS are addressed in Section 6.3.4.

The SIS is redundant and no single failure compromises the system safety functions. Vital power can be supplied from either the onsite or offsite power systems, as described in Chapter 8. Results of the single failure evaluation are summarized in Table 6.3-6—Safety Injection System Failure Modes and Effects Analysis. The most limiting single active failure for the SIS, assumed to occur at the onset of the design basis LOCA event, is the complete loss of one train. The redundancy incorporated into the system design allows the SIS to fulfill its safety function in spite of such failure, as further addressed in Section 15.6.5. The availability of four separate hot-leg connections, one for each of the SIS trains, preserves the hot-leg injection function to mitigate boron precipitation and steaming from the LOCA break.

As a conservative verification of the adequacy of the SIS design, the effects of a single passive failure during the long-term accident recovery phase are also considered. The most limiting passive failure is the loss of a coolant supply path, which might occur in the unlikely event of debris plugging of one of the sump suction sources or rupture of one of the supply lines. The redundant SIS design allows the unaffected trains to continue to provide long-term cooling in spite of such a passive failure. The addition of guard pipes on piping between the sump connections and the sump three-way isolation valves provides additional protection against flooding due to passive failure of the pipe upstream of the isolation valve.

The redundancy of the design extends to the capability to isolate affected sections of the individual trains as required. Since the critical function of the SIS is RCS injection, automatic containment isolation of the system, which could adversely impact the function of the system, is not provided. Combined manual and passive isolation capability, however, is provided as described in Section 6.2.4.

The SIS valves inside containment are located above the maximum floor flooding level which protects the valve motor operators from submersion following a LOCA. The RB flooding analysis is described in Section 3.4.3.3. The SIS suction piping is continuously vented to maintain it full of coolant whenever the system is required to be operable to prevent loss of pump suction pressure that could result from accumulation of gases in the piping. Components of the SIS, including those for its support and auxiliary equipment, are designed, procured, installed, and maintained to the appropriate quality and reliability standards. These quality standards, coupled with the system redundancy and physical and electrical separation, allow the SIS to fulfill the design objectives presented in Section 6.3.1.

The RB floor drains direct leakage within the containment, up to an accumulation of two inches depth, to the RB sump where it is monitored, quantified, and processed as liquid waste. The RB floor drains are part of the NIDVS described in Section 5.2.5. Accumulation of leakage in containment greater than two inches depth, which is indicative of a LOCA, flows into the IRWST where it is available for accident response. The relatively low volume of the RB drains, in comparison to that of the IRWST, allows mixing of coolant during injection and recirculation so that no areas accumulate very high to low pH solutions.

The IRWSTS design responds to the post-LOCA ECCS sump performance issues of GSI-191 in accordance with the guidance of RG 1.82. The IRWSTS deters post-accident debris accumulation and SIS sump strainer blockage, in accordance with the expectations of RG 1.82, by:

- Minimizing the post-accident debris source term. The RCS piping and components, and other potentially insulated systems or components within a zone of influence, are insulated with RMI, and or no fibrous or microporous insulation.

Due to its high density, RMI is not susceptible to transport and therefore does not contribute to strainer head loss.

- Providing a three-tiered debris retention design. The combination of weirs/trash racks and retaining baskets are effective in retaining most post-accident debris. Furthermore, the sump strainers (the third stage of the three-tiered debris retention design) have a large screen surface area to accommodate the small amount of debris that reaches it. The full coverage screens and retention baskets, which are rigidly mounted to the IRWST floor, limit bypass of debris into the suction lines.

The design features addressing GSI-191 and the performance evaluations are further described in Section 6.3.2.2.2 and Reference 19. Reference 19 also describes the component test program and compares the design to the regulatory positions of RG 1.82 and the information requested in GL 2004-02. Additional component design and evaluation parameters for downstream ex-vessel components exposed to post-LOCA fluids are given in Appendix G of Reference 19.

6.3.2.6 Protection Provisions

The four independent SIS trains are individually housed in four separate, Seismic Category I, reinforced concrete structures as described in Section 3.8.4. Since the SIS itself is Seismic Category I, the system is protected from potential earthquake damage. The rugged structures also protect the system from other natural phenomena and external hazards. The design of the system includes margin to safely accommodate displacement due to thermal stresses and limited movement due to operational anomalies or external stimuli. Physical separation is provided for the SIS/RHR system redundant components, including cross connects, located within the RB such that local effects of any internal hazard (e.g., pipe whip) are restricted to one train. Specific layout provisions, arrangement of components, or design features prevent any global effects from an internal hazard affecting the operability of system components inside containment. Refer to Section 3.10 for seismic qualification of equipment. Protection against other natural phenomena is addressed in Sections 3.3 and 3.4. Missile protection and protection against dynamic effects are addressed in Sections 3.5 and 3.6, respectively. Section 9.5.1 and Appendix 9A address fire protection, Section 3.11 addresses environmental qualification of equipment, and Section 3.9 reviews the thermal and displacement stresses.

6.3.2.7 Provisions for Performance Testing and Inspection

The general installation and design of the SIS provides ready accessibility for testing and inspection. Process and auxiliary fluid paths are isolable and instrumented to accommodate maintenance and testing of the valves, instrumentation, and other critical SIS components, with multiple minimum flow paths provided for dynamic testing of the SIS pumps. The redundancy provided by the four separate trains of the system allows such activities to be performed online as well as during scheduled maintenance or outages. The arrangement of the piping and components is shown in Figures 6.3-1 through 6.3-3. Performance testing is addressed in Section 6.3.4.

6.3.2.8 Manual Actions

The SIS injects automatically in response to the safety injection signal and requires no operator intervention to accomplish its function. The emergency coolant supply is enclosed within the containment and is constantly replenished by recirculated coolant flow, therefore no operator action is required to provide the continuous supply of coolant or the removal of decay heat during the injection phase.

To prevent boron precipitation and mitigate steaming from the break, manual switchover to hot-leg injection is required approximately one hour into the event. This represents the response to the most severe of the postulated events, such as the LBLOCA.

For less severe events such as SBLOCA, automatic action is adequate to manage the event. After completion of the initial automatic response, it may be beneficial to manage the event with deliberate operator action. For instance, while the protection system initiates reactor trip and SIS startup following an SBLOCA, it may be possible, depending on the scale of the event, to identify and isolate the failed component, thereby terminating the event and allowing safe shutdown without further challenges to the safety systems. Such actions are in accordance with approved procedures developed as described in Section 13.5.2.

6.3.3 Performance Evaluation

During normal, at-power operation, the SIS is idle but configured for rapid automatic or on-demand response. Four cold-leg injection and IRWST suction flow paths are open, the hot-leg suction or alternate injection path is isolated, and the CCWS and SCWS cooling function for the SIS pumps and equipment area is in service or available to start on receipt of a demand signal. The SIS is isolated from the RCS cold legs by its boundary check valves which are back-seated by RCS pressure.

During shutdown cooling operations, the MHSI train is maintained in standby for RCS leakage makeup, with CCWS available for pump and area cooling. The large mini flow valve remains open to limit MHSI injection pressure and flowrate to levels appropriate for the shutdown condition.

Section 6.3.1 lists those postulated events for which SIS response is required. The most demanding SIS performance response, which bounds the response required for those events listed in Section 6.3.1, is the response to the range of SBLOCAs and the response to the most limiting LBLOCA. For that reason, SIS performance is evaluated for only these two most limiting events.

This analysis shows that the performance of the SIS during these limiting events limits the accident consequences to accommodate recovery, protect the health and safety of the public, and meet the regulatory requirements specified in Section 6.3.1. The event sequence and analysis, including equipment actuation and response times, and flow delivery curves, are described in Section 15.6.5.

6.3.3.1 Small Break LOCA

The most limiting SBLOCA is a break with a cross-sectional area of up to approximately 0.5 ft^2 in the cold leg between the SIS injection location and the reactor pressure vessel, with coincident LOOP. Such an event may not immediately challenge the SIS if the reactor coolant loss can be made up by the CVCS. The loss of primary coolant eventually results in a decrease in primary system pressure and pressurizer level, sequentially triggering a reactor and turbine trip, and closing the main feedwater full load isolation valves. Upon receipt of an SIS actuation signal, a partial cooldown of the secondary system, and thus the RCS, is initiated. During this sequence, the steam generators are fed by the emergency feedwater system, which is actuated by protection system signals.

The SIS actuates on low pressurizer pressure and automatically starts the MHSI and LHSI pumps. During the partial cooldown, the RCS pressure decreases sufficiently to allow MHSI injection into the cold legs. The partial cooldown is performed by available steam generators via steam dump to the atmosphere. The protection system automatically decreases the main steam relief train setpoints down to a fixed pressure that is low enough to permit MHSI injection, but high enough to prevent core recriticality due to low RCS temperature. For the smallest of these breaks, the RCS leakage, still in liquid form, does not remove sufficient coolant mass to offset injection flow and RCS depressurization stops at the end of the partial cooldown. If the MHSI flowrate is insufficient to compensate for the break flowrate, the RCS inventory continues to decrease. The break flowrate decreases as the void fraction in the cold legs increases. When the break flow changes to single phase steam, the ratio between steam production due to core decay heat and steam break venting changes and the break size is the dominant parameter for the depressurization sequence.

In case of the smallest breaks, condensation in the steam generator tubes, in combination with direct steam venting from the break, eventually reduces production of steam in the core to the point that the RCS saturation pressure plateaus slightly above the steam generator secondary side pressure. In the case of larger small breaks, steam venting is sufficient that the RCS depressurizes, regardless of the steam generator secondary side temperature, down to the point where accumulator injection, and eventually LHSI injection, occurs.

6.3.3.2 Large Break LOCA

The most limiting LBLOCA is a break in the cold-leg piping between the RCP and the reactor vessel for the RCS loop containing the pressurizer. The break is assumed to open instantaneously. For this break, rapid depressurization of the primary system occurs. Automatic partial cooldown (via the secondary side) is unnecessary due to the rapid depressurization caused by the break.

SIS actuates on receipt of a low pressurizer pressure signal. The most limiting single failure for this event is the loss of one SIS train (i.e., loss of one MHSI pump and one LHSI pump). Because one other train is conservatively assumed to be unavailable due to maintenance or other activity, only two pump trains are available for the event. Four accumulators are assumed to be available, as accumulator maintenance is prohibited during power operation and the downstream accumulator isolation valves are secured open (breakers racked out) to protect against active single failure.

When the RCS pressure falls below the accumulator pressure, fluid from the accumulators is injected into the cold legs. SIS flow injects into the RCS when system startup-time delays have elapsed and primary system pressure falls below the respective shutoff heads of the MHSI and LHSI systems. While some of the ECCS flow bypasses the core and goes directly out of the break, the downcomer and lower plenum gradually refill. During this refill phase, heat is primarily transferred from the hotter fuel rods to cooler fuel rods and structures by radiative heat transfer.

When the lower plenum is refilled to the bottom of the fuel rod heated length, the refill phase ends and the reflood phase begins. The ECCS fluid flowing into the downcomer provides the driving head to move coolant through the core. As the mixture level moves up the core, steam is generated and liquid is entrained. As this entrained liquid is carried into the SGs, it vaporizes because of the higher temperature in the SGs. This causes steam binding, which reduces the core reflooding rate. The fuel rods are cooled and quenched by radiation and convective heat transfer as the quench front moves up the core. Long term recirculation cooling is maintained by the LHSI function of the SIS.

6.3.3.3 NPSH Evaluation

An evaluation of the MHSI and LHSI pumps demonstrates sufficient NPSH is available during postulated DBAs.

The basic relationship that describes available NPSH is:

$$NPSH_a = h_{atm} + h_{static} - h_{loss} - h_{vp}$$

Where:

h_{atm}= the head on the liquid surface resulting from the pressure in the atmosphere above the IRWST

h_{static} = the head resulting from the difference in elevation between the liquid surface and the centerline of the pump suction

h_{loss} = the head loss resulting from fluid friction and fittings in the flowpath to the pump suction flange

h_{vp} = the head equivalent to the vapor pressure of the water at the water temperature

The head equivalent to the vapor pressure of the water at the water temperature varies with temperature. For IRWST water properties during the time period prior to the IRWST reaching 212°F, the analysis assumes subcooled liquid at 1 atm, which was the containment pressure before the accident. When IRWST temperature is greater than 212°F, the containment pressure is set equal to the IRWST liquid vapor pressure.

This evaluation includes the effects of IRWST temperature, sump screen resistance with debris, pump performance with uncertainties, and uncertainties in hydraulic resistances. The uncertainties associated with pump performance and hydraulic resistances include:

- Friction loss factors for piping and fittings;
- Friction loss factors for flow coefficient (C_V) values of valves;
- Pump wear;
- Pump manufacturing tolerances;
- Plant instrument uncertainties;
- Grid frequency variation.

IRWST temperatures are calculated using RELAP5/B&W (Reference 16) to determine the mass and energy release, and GOTHIC (Reference 17) to determine the containment and IRWST responses. The IRWST temperatures are calculated conservatively by mixing the condensed liquid in the containment with the IRWST water. The limiting case is the double-ended guillotine (DEG) hot-leg break, Figure 6.3-7—IRWST LOCA Temperature Response. The peak IRWST temperature is calculated to be 246.2°F. The limiting evaluation of NPSH credits containment accident pressure since it conservatively assumes the IRWST liquid is at the saturation pressure corresponding to the peak calculated IRWST temperature.

Since containment accident pressure is credited in determining available NPSH, an evaluation of the contribution to plant risk from inadequate containment pressure was performed based on the PRA model, as described in Chapter 19. The evaluated risk associated with crediting containment accident pressure was determined to be low, consistent with the conclusions in Reference 20.

The SIS pump NPSH evaluation for LBLOCA events is performed using the maximum pump flow head-capacity curves (with uncertainties biased towards enhanced pump performance), minimum system resistances, screen resistance in a debris laden sump, and an IRWST level based on conservatively calculated liquid hold up in the containment.

Required NPSH is specified by the pump vendor as a result of factory testing as the value of NPSH which results in a 3-percent drop in pump discharge head ($NPSH_{r3\%}$). $NPSH_r$ is a property of the pump itself. Following the guidance of SECY-11-0014 (Reference 20), uncertainties associated with $NPSH_r$ are used to determine the effective $NPSH_r$ ($NPSH_{reff}$), where:

$$NPSH_{reff} = (1 + \text{uncertainty})\ NPSH_{r3\%}$$

The following uncertainty factors that affect $NPSH_r$ developed during pump testing were considered:

1. The $NPSH_r$ varies with changes in pump speed caused by motor slip.
2. The $NPSH_r$ decreases with increasing water temperature.
3. Incorrectly designed field suction piping adversely affects the $NPSH_r$.
4. The air content of the water used in the vendor's test may be lower than that of the pumped water in the field.
5. Wear ring leakage impacts $NPSH_r$.

The $NPSH_r$ curves have not been adjusted to consider the positive impact of increasing water temperature (Item 2). This results in a conservative value for $NPSH_r$. A 21 percent margin has been applied to account for the effects of the other four uncertainty factors. This margin is consistent with that used in operating plants. Therefore:

$$NPSH_{reff} = (1 + 0.21)NPSH_{r3\%}$$

$$NPSH_{margin} = NPSH_a - NPSH_{reff}$$

For the LBLOCA event, MHSI and LHSI flow are credited to reflect core quench. In Section 15.6.5, the LBLOCA event was analyzed over a period of approximately 800 seconds. During this time frame, the MHSI and LHSI pumps maintain adequate NPSH margin (see Figure 6.3-8—LHSI in LBLOCA and Figure 6.3-9—MHSI in

LBLOCA). The MHSI and LHSI NPSH margin is calculated under the following conditions:

- IRWST temperature of 135°F.
- IRWST level elevation at -9.008 ft.
- Minimum static head of 17.2 ft.
- Strainer head loss including debris, of 1.98 ft.
- RCS break pressure of 45 psia (RCS break remains at or above this pressure until after PCT has been reached).
- Containment pressure reduced to 1 atm (containment pressure prior to the accident).
- Enhanced pump performance and degraded system resistances.

For the LBLOCA, after approximately 1.54 hours IRWST temperature exceeds 212°F. However, before reaching this temperature, operator action for termination of MHSI flow when the core outlet remains saturated can proceed when total LHSI flow exceeds the minimum flow rate specified by accident analysis. In some scenarios, such as the containment analysis case of only two trains of SI in operation, continued MHSI flow is necessary and will not be terminated. Therefore in this NPSH analysis both LHSI and MHSI pumps are assumed to operate for the duration of the event.

During the period that IRWST temperature exceeds 212°F, the atmospheric pressure term is set equal to the IRWST liquid vapor pressure and is used in calculating $NPSH_a$ During this period, the following equation applies:

$$NPSH_a = h_{static} - h_{loss}$$

The liquid temperature continues to increase until about 3 hours into the event when the heat removal capacity of the LHSI heat exchangers exceeds the heat addition to the IRWST by the liquid break flow.

The most limiting case for NPSH for the LHSI pump is 2764 gpm during simultaneous injection, saturated liquid in the IRWST, and saturation pressure both in containment and at the break at 212°F as shown in Figure 6.3-8—LHSI in LBLOCA. For this case, the MHSI pump is switched off so the LHSI pump discharge flow rate equals the total suction flow rate. The results are:

$$h_{atm} = h_{vp}$$

$$h_{static} = 17.487 \text{ ft}$$

h_{loss} = 2.11 ft (strainer + debris)

h_{loss} = 8.53 ft (total = debris + strainer + piping)

LHSI $NPSH_a$ = 8.96 ft

LHSI $NPSH_{reff}$ = 8.17 ft

LHSI NPSH Margin = 0.79 ft or 9.7 percent

The most limiting case for NPSH for the MHSI pump is 1111 gpm during simultaneous injection, saturated liquid in the IRWST, and saturation pressure both in containment and at the break at 212°F, as shown in Figure 6.3-9—MHSI in LBLOCA. For this case, the total suction flow rate is 3750 gpm because the MHSI and LHSI systems operate together at the beginning of a LOCA. The analyzed LHSI flow rate is 2643 gpm. The results are:

$h_{atm} = h_{vp}$

h_{static} = 17.487 ft

h_{loss} = 2.11 ft (debris + strainer)

h_{loss} = 5.97 ft (total = debris + strainer + piping)

MHSI $NPSH_a$ = 11.52 ft

MHSI $NPSH_{reff}$ = 11.51 ft

MHSI NPSH Margin = 0.009 ft or 0.08 percent

The instrument uncertainty on IRWST level is 0.33 ft (4.0 inches). LHSI margin is never this small. The period during which the MHSI NPSH margin to $NPSH_{reff}$ is less than 0.33 ft is about 1.2 hours.

The SIS lineup for evaluating the most limiting case for NPSH is when only one SIS train is injecting to the RCS considering one train is unavailable due to a single failure; another train is out for maintenance, and another train feeds the broken loop.

Most significant cavitation erosion effects occur between NPSH ratios of 1.2 to 1.6. A short period of approximately seven hours, during which the NPSH ratios are in this range, does not significantly affect MHSI or LHSI pump long term capability, as shown in Figure 6.3-10—LHSI in LBLOCA - Cavitation Erosion and Figure 6.3-11—MHSI in LB LOCA - Cavitation Erosion.

6.3.4 Tests and Inspections

Refer to Section 14.2 (Test abstract #014, #015, #016, #022, #175, and #177) for initial plant testing. Applicable guidance from RG 1.79 is incorporated in the initial plant testing described in Section 14.2.

Surveillance Requirements 3.5.1, 3.5.2, 3.5.3, and 3.5.4 in Chapter 16 describe the SIS surveillance requirements.

The installation and design of the SIS and IRWSTS provides accessibility for periodic testing and in-service inspection. Sections 3.9.6, 5.2.4, and 6.6 address the pre-service and in-service testing and inspection programs for the SIS.

6.3.5 Instrumentation Requirements

The SIS trains and IRWSTS are monitored and controlled from the main control room through the instrumentation and control systems. The instrumentation and control systems process and display information in the main control room, and actuate the safety injection function as required by plant process safety parameters.

Operator intervention to protect the SIS equipment is required in the event of alarms that indicate unacceptable parameters, such as high bearing oil, motor winding, or motor air temperatures, or loss of suction head. Such conditions alarm or indicate in the control room.

The SIS pumps start automatically on receipt of a safety injection signal, with independent power supply for each train provided by the emergency power supply system. When the permissive P12 is not validated (RCS pressure is at or near that for power operation), the SIS pumps start on the receipt of a low pressurizer pressure signal. When the permissive P12 is validated (RCS pressure indicates reactor shutdown and cooldown in progress), the SIS pumps start on the receipt of a low RCS delta-Psat signal (difference between the RCS hot-leg actual pressure and the RCS hot-leg saturation pressure). In the event a LOCA occurs when permissive P15 is validated (LHSI is in RHR mode with no RCPs in operation), the MHSI pumps start automatically on loss of RCS level. Permissive signals are described in Section 7.2.1.3.

On receipt of a safety injection signal, the motor operated valves in the injection paths receive a signal to open and the hot-leg suction or alternate injection line isolation valves receive a signal to close.

The monitored parameters of the IRWST are water level (for leakage detection and inventory monitoring), water temperature, sump screen differential pressure, and the SIS suction line double (guard) pipe pressure.

I&C for the SIS, as well as its respective permissives, are described in Chapter 7. Applicable guidance from RG 1.47 is incorporated in the design of the SIS I&C described in Chapter 7.

6.3.6 References

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20. NRC SECY Paper, “Use of Containment Accident Pressure in Analyzing Emergency Core Cooling System and Containment Heat Removal System Pump Performance in Postulated Accidents,” SECY-11-0014, January 31, 2011.

21. ANP-10329, Revision 0, “U.S. EPR Mitigation Strategies for an Extended Loss of AC Power Event Technical Report,” AREVA NP Inc., May 2013.

Table 6.3-1—Accumulators Design and Operating Parameters

Parameter	Value
Number of units	4 (one per train)
Material	Austenitic stainless steel
Design pressure	800 psig
Normal operating pressure	667.2 psig
Maximum operating pressure	696.2 psig
Minimum operating pressure	638.2 psig
Design temperature	140°F
Nominal operating temperature	90.5°F
Maximum operating temperature	122.0°F
Minimum operating temperature	59.0°F
Maximum liquid volume	1412.6 ft^3
Minimum liquid volume	1236.0 ft^3
Maximum nitrogen volume	706.3 ft^3
Minimum nitrogen volume	529.7 ft^3
Total accumulator volume	1942.3 ft^3
Minimum boron enrichment	37% of ^{10}B
Maximum boron concentration	1900 ppm
Minimum boron concentration	1700 ppm
Overall accumulator height	353.6 in
Accumulator pipe internal diameter	11.75 in
Accumulator discharge line piping wall thickness	0.5 in
Minimum accumulator fL/D + K (for flow area = 0.3941 ft2 and f = 0.014)	3.71

Note:

1. Physical dimensions are approximate values.

Table 6.3-2—Low Head Safety Injection Pumps Design and Operating Parameters

Parameter		Value	
Number		4	
Type/arrangement		Centrifugal/horizontal	
Type of fluid		primary coolant; post-LOCA downstream fluid	
Design pressure/temperature		1160 psig/360°F	
Normal flowrate (approximate)		2200 gpm	
Normal flow head (approximate)		480 ft	
Minimum flowrate (approximate)		530 gpm	
Flow head at minimum flowrate (approximate)		750 ft	
Nominal motor power (approximate)		340 kW	
LHSI Pump Characteristics			
Pump Flow (gpm)	**TDH (ft)**	**$NPSH_{r3\%}$ (ft)**	**$NPSH_{reff}$ (ft)**
0.0	782	2.5	3.0
440	760	2.8	3.4
880	718	3.2	3.9
1320	656	3.8	4.6
1760	575	4.4	5.3
2200	480	5.3	6.4
2640	356	6.2	7.5
3220	108	8.2	9.9

Table 6.3-3—Medium Head Safety Injection Pumps Design and Operating Parameters

Parameter	Value
Number	4
Type/arrangement	Centrifugal/horizontal
Type of fluid	primary coolant; post-LOCA downstream fluid
Design pressure/temperature	1525 psig/250°F
Normal flowrate (approximate)	600 gpm
Normal flow head (approximate)	2260 ft
Minimum flowrate (approximate)	165 gpm
Flow head at minimum flowrate (approximate)	3200 ft
Nominal motor power (approximate)	455 kW

MHSI Pump Characteristics			
Pump Flow (gpm)	TDH (ft)	$NPSH_{r3\%}$ (ft)	$NPSH_{reff}$ (ft)
0.0	3281	N/A	N/A
220	3146	7.4	9.0
440	2751	4.7	5.7
660	2096	5.1	6.2
880	1182	6.7	8.1
1110	328	8.6	10.4

Table 6.3-4—LHSI Heat Exchanger Design and Operating Parameters

Parameter	Value
Type	U-Tube, horizontally mounted
Number of units	4
Type of fluid (tube side)	Primary coolant; post-LOCA downstream fluid
Type of fluid (shell side)	Cooling water from CCWS
Material (tube side)	Austenitic stainless steel
Material (shell side)	Ferritic steel
Design pressure (tube side)	1160 psig
Design pressure (shell side)	175 psig
Design temperature (tube side)	360°F
Design temperature (shell side)	225°F
CCWS maximum inlet temperature (normal cooldown)	100.4°F
CCWS maximum inlet temperature (design basis accident)	113°F
LHSI flowrate – injection mode LBLOCA (including minimum flow)	392.4 lb_m/s
LHSI flowrate – RHR operation (minimum flow line closed)	330.7 lb_m/s
CCWS flowrate Trains 1 and 4 (shell side)	828.9 lb_m/s
CCWS flowrate Trains 2 and 3 (shell side)	608.5 lb_m/s
Heat transfer coefficient (UA value)	3.5361 x 10^6 BTU/(hr °F)

Note:

1. Physical dimensions are approximate values.

Table 6.3-5—Total Debris Source Term

Material	Estimated U.S. EPR Maximum
RMI	2119 ft^2
Latent debris	150 lb
Microporous insulating material	1 ft^3
Inorganic zinc	959 lb
Qualified epoxy coatings	126 lb
Unqualified epoxy coatings	250 lb

Table 6.3-6—Safety Injection System Failure Modes and Effects Analysis
Sheet 1 of 10

Component	Component Function	Failure Mode	Failure Mechanism	Failure Symptoms/ Effects	Can SIS/RHRS Satisfy Mission Success Criteria?
MHSI Pump 30JND10 AP001 30JND20 AP001 30JND30 AP001 30JND40 AP001	Develop required flow and head for safety injection	a) Failure to start	Mechanical/Electrical/ I&C	No flow to the RCS.	Yes, as it only affects one train.
		b) Failure to run	Mechanical/Electrical	No flow to the RCS	Yes, as it only affects one train.
		c) Excessive flow	Mechanical	Risk of run-out for the MHSI pump.	Yes, as it only affects one train. Note that orifice 30JND10/20/30/ 40 BP003 provides a controlled flow.
		d) Inadequate flow	Mechanical	Insufficient flow to the RCS.	Yes, as it only affects one train.
IRWSTS 3-Way Isolation Valve 30JNK10 AA001 30JNK20 AA001 30JNK30 AA001 30JNK40 AA001	Isolation of SIS suction line from the IRWSTS	a) Spurious closure	Electrical/I&C	No flow to the RCS.	Yes, as it only affects one train.
MHSI Outside Containment Isolation Valve 30JND10 AA002 30JND20 AA002 30JND30 AA002 30JND40 AA002	MHSI outside containment isolation	a) Spurious closure	Electrical/I&C/Operator Action	No flow to the RCS.	Yes, as it only affects one train.

**Table 6.3-6—Safety Injection System Failure Modes and Effects Analysis
Sheet 2 of 10**

Component	Component Function	Failure Mode	Failure Mechanism	Failure Symptoms/ Effects	Can SIS/RHRS Satisfy Mission Success Criteria?
MHSI Small Miniflow Line Isolation Valve 30JND10 AA004 30JND20 AA004 30JND30 AA004 30JND30 AA004	Isolation of the MHSI small miniflow line	a) Spurious closure	Electrical/I&C	Potential pump failure due to overheating.	Yes, as it only affects one train.
MHSI Large Miniflow Line Isolation Valve 30JND10 AA005 30JND20 AA005 30JND30 AA005 30JND40 AA005	Isolation of the MHSI large miniflow line	a) Spurious opening	Electrical/I&C	Insufficient head to the RCS cold leg, potentially restricting safety injection to the core due to higher downstream pressure.	Yes, as it only affects one train.
		b) Fails close	Mechanical/Electrical/ I&C	Impediment of MHSI injection with reduced discharge head when LHSI is in RHR mode.	Yes, as it only affects one train. MHSI pumps are terminated in (very) SBLOCA for RHR connection. For larger SBLOCA, RHR connection is not required.
MHSI Control Valve 30JND10 AA103 30JND20 AA103 30JND30 AA103 30JND40 AA103	Manual throttling of the MHSI discharge flowrate during long term post-accident management	a) Spurious closure	Electrical/I&C	No flow to the RCS.	Yes, as it only affects one train.

Table 6.3-6—Safety Injection System Failure Modes and Effects Analysis
Sheet 3 of 10

Component	Component Function	Failure Mode	Failure Mechanism	Failure Symptoms/ Effects	Can SIS/RHRS Satisfy Mission Success Criteria?
Primary Coolant Injection Outside Containment Isolation Valve 30JND11 AA012	Primary coolant injection outside containment isolation	a) Spurious opening	Electrical/I&C/Operator Action	Backflow into primary coolant injection pump.	Yes, inside containment isolation swing check valve 30JND10 AA007 still provides containment isolation.
Dead Leg Pressurization Valve 30JNG15 AA001 30JNG25 AA001 30JNG35 AA001 30JNG45 AA001	Isolation of the cold-leg side of the dead leg pressurization line	a) Spurious opening	Electrical/I&C	No impact.	Yes. Isolation to the RCS hot leg is provided by 30JNG15/25/35/45 AA002 while isolation to the CVCS letdown line is provided by 30JNG15/25/35/45 AA003.
RCS Suction Line Pressurization Valve 30JNG15 AA002 30JNG25 AA002 30JNG35 AA002 30JNG45 AA002	Isolation of the hot-leg side of the dead leg pressurization line	a) Spurious opening	Electrical/I&C	No impact.	Yes. Isolation to the RCS hot leg is provided by 30JNG15/25/35/45 AA001.
Dead Leg Pressure Bypass Isolation Valve 30JNG15 AA003 30JNG25 AA003 30JNG35 AA003 30JNG45 AA003	Isolation between the dead leg pressurization line and the CVCS letdown line	a) Spurious opening	Electrical/I&C	No impact.	Yes. Isolation to the CVCS letdown line is provided by 30JNG15/ 25/35/45 AA001.

Table 6.3-6—Safety Injection System Failure Modes and Effects Analysis
Sheet 4 of 10

Component	Component Function	Failure Mode	Failure Mechanism	Failure Symptoms/ Effects	Can SIS/RHRS Satisfy Mission Success Criteria?
LHSI Pump 30JNG10 AP001 30JNG20 AP001 30JNG30 AP001 30JNG40 AP001	Develop required flow and head for safety injection and residual heat removal	a) Failure to start	Mechanical/Electrical/ I&C	No flow to the RCS.	Yes, as it only affects one train.
		b) Failure to run	Mechanical/Electrical	No flow to the RCS.	Yes, as it only affects one train.
		c) Excessive flow	Mechanical	Risk of run-out for the LHSI pump.	Yes, as it only affects one train.
		d) Inadequate flow	Mechanical	Insufficient flow to the RCS.	Yes, as it only affects one train.
LHSI Suction Isolation Valve 30JNG10 AA001 30JNG20 AA001 30JNG30 AA001 30JNG40 AA001	LHSI isolation on suction line from the IRWSTS	a) Spurious closure	Electrical/I&C	No flow to the RCS.	Yes, as it only affects one train.
LHSI HX Bypass Control Valve 30JNA10 AA101 30JNA20 AA101 30JNA30 AA101 30JNA40 AA101	To keep RHR flowrate constant	a) Spurious opening	Electrical/I&C	No impact on safety injection.	Yes.
LHSI Control Valve 30JNG10 AA106 30JNG20 AA106 30JNG30 AA106 30JNG40 AA106	Manual throttling of the LHSI discharge flowrate during long term post-accident management	a) Spurious closure	Electrical/I&C	No flow to the RCS.	Yes, as it only affects one train.

Table 6.3-6—Safety Injection System Failure Modes and Effects Analysis
Sheet 5 of 10

Component	Component Function	Failure Mode	Failure Mechanism	Failure Symptoms/ Effects	Can SIS/RHRS Satisfy Mission Success Criteria?
LHSI HX Main Control Valve 30JNG10 AA102 30JNG20 AA102 30JNG30 AA102 30JNG40 AA102	Control of the LHSI HX temperature	a) Spurious closure	Electrical/I&C	No flow to the RCS.	Yes, as it only affects one train.
LHSI Outside Containment Main Isolation Valve 30JNG10 AA060 30JNG20 AA060 30JNG30 AA060 30JNG40 AA060	Outside containment isolation on LHSI main discharge line	a) Spurious closure during cold-leg injection	Electrical/I&C	Restricted flow to the RCS.	Yes, as it only affects one train.
		b) Spurious opening during hot-leg injection	Electrical/I&C	Impediment of hot-leg safety injection.	Yes, as it only affects one train.
LHSI Outside Containment Bypass Isolation Valve 30JNG10 AA061 30JNG20 AA061 30JNG30 AA061 30JNG40 AA061	Outside containment isolation on LHSI bypass discharge line	a) Spurious closure during cold-leg injection	Electrical/I&C	No impact.	Yes.
		b) Spurious closure during hot-leg injection	Electrical/I&C	Potential pump failure due to overheating when LHSI pump is on hot-leg injection mode.	Yes, as it only affects one train.

Table 6.3-6—Safety Injection System Failure Modes and Effects Analysis
Sheet 6 of 10

Component	Component Function	Failure Mode	Failure Mechanism	Failure Symptoms/ Effects	Can SIS/RHRS Satisfy Mission Success Criteria?
LHSI Hot-Leg Injection Isolation Valve 30JNG12 AA001 30JNG22 AA001 30JNG32 AA001 30JNG42 AA001	Isolation of connection line between cold-leg and hot-leg injection lines	a) Spurious opening during cold-leg injection	Electrical/I&C	No impact.	Yes. RCPB isolation valves 30JNA10/20/30/ 40 AA001/AA002 and 30JNG15/25/35/45 AA004 prevent inadvertent injection into the hot leg.
		b) Spurious closure during hot-leg injection	Electrical/I&C	No flow to the RCS.	Yes, as it only affects one train.
LHSI Radial Miniflow Line Check Valve 30JNG10 AA003 30JNG20 AA003 30JNG30 AA003 30JNG40 AA003	Isolation of the LHSI radial miniflow line	a) Spurious opening	Electrical/I&C	No impact on safety injection due to orifice 30JNGi0 BP001.	Yes.
LHSI Tangential Miniflow Line Check Valve 30JNG10 AA004 30JNG20 AA004 30JNG30 AA004 30JNG40 AA004	Isolation of the LHSI tangential miniflow line	a) Spurious closure	Electrical/I&C	Potential pump failure due to overheating.	Yes, as it only affects one train.

Table 6.3-6—Safety Injection System Failure Modes and Effects Analysis
Sheet 7 of 10

Component	Component Function	Failure Mode	Failure Mechanism	Failure Symptoms/ Effects	Can SIS/RHRS Satisfy Mission Success Criteria?
SAHRS-IRWST System Isolation Valve 30JNG40 AA007	Isolation of the SAHRS backflushing connection line from the SIS suction line	a) Spurious opening	Electrical/I&C	No impact.	Yes. Isolation of the SAHRS backflushing connection line is still provided by the second isolation valve 30JNG40 AA008.
SAHRS-IRWST System Isolation Valve 30JNG40 AA008	Isolation of the SAHRS backflushing connection line from the SIS suction line	a) Spurious opening	Electrical/I&C	No impact.	Yes. Isolation of the SAHRS backflushing connection line is still provided by the first isolation valve 30JNG40 AA007.
LHSI HX Bypass Isolation Valve on Purification Line to CVCS 30JNA30 AA004 30JNA40 AA004	Isolation of the low-pressure purification letdown line	a) Spurious opening	Electrical/I&C	No impact.	Yes. Isolation is provided by 30KBA14 AA004 and/or 30KBA14 AA106 (both valves normally closed). Note that 30KBA14 AA004 is on a different electrical bus as that of 30KBA14 AA106.

Table 6.3-6—Safety Injection System Failure Modes and Effects Analysis
Sheet 8 of 10

Component	Component Function	Failure Mode	Failure Mechanism	Failure Symptoms/ Effects	Can SIS/RHRS Satisfy Mission Success Criteria?
LHSI HX Bypass Throttle Valve on Purification Line to CVCS 30JNA30 AA103 30JNA40 AA103	Throttling of flow into the low-pressure purification letdown line	a) Spurious opening	Electrical/I&C	No impact.	Yes. Isolation is provided by 30KBA14 AA004 and/or 30KBA14 AA106 (both valves normally closed). Note that 30KBA14 AA004 is on a different electrical bus as that of 30KBA14 AA106.
Accumulator Isolation Valve 30JNG13 AA008 30JNG23 AA008 30JNG33 AA008 30JNG43 AA008	Isolation of the accumulator injection line	a) Spurious closure	Electrical/I&C	No flow to the RCS.	Yes, as it only affects one train. Note that this can only occur below power operation, as at-power, the electrical buses of valve 30JNG13/ 23/33/43 AA008 are racked-out.
		b) Fails open	Mechanical/Electrical/ I&C	Failure to close when accumulator is impeding RCS depressurization, resulting in increased RHR connection time.	Yes, with an accepted increased in RHR connection time.
Emergency Diesel Generator (EDG) 30XKA10/20/30/40	Provide emergency power to one SIS/RHRS train in the event of a LOOP	a) Failure to start	Mechanical/Electrical/ I&C	Loss of interruptible emergency power to one SIS/RHRS train.	Yes, as it only affects one train (LOOP is assumed in this case).
		b) Failure to run	Mechanical	Loss of interruptible emergency power to one SIS/RHRS train.	Yes, as it only affects one train (LOOP is assumed in this case).

Table 6.3-6—Safety Injection System Failure Modes and Effects Analysis
Sheet 9 of 10

Component	Component Function	Failure Mode	Failure Mechanism	Failure Symptoms/ Effects	Can SIS/RHRS Satisfy Mission Success Criteria?
Emergency Diesel Generator (EDG) on Alternate Feed Mode 30XKA10/20/30/40	Provide emergency power to one SIS/RHRS train and to selected equipment of a second SIS/RHRS train in the event of a LOOP	a) Failure to start	Mechanical/Electrical/ I&C	Loss of interruptible power to two SIS/RHRS trains.	Yes, as only two trains are required (one train feeding the broken loop and another providing core cooling function) to satisfy mission success criteria (LOOP is assumed in this case).
		b) Failure to run	Mechanical	Loss of interruptible power to two SIS/RHRS trains.	Yes, as only two trains are required (one train feeding the broken loop and another providing core cooling function) to satisfy mission success criteria (LOOP is assumed in this case).
CCWS Supply Train KAA	Provide cooling for the LHSI HX, LHSI pumps Trains 2 and 3 (motor cooler and sealing medium), and MHSI pumps (motor cooler)	a) Failure to operate	Mechanical/Electrical/ I&C	Loss of cooling for the mentioned components.	Yes, as it only affects one train.

Table 6.3-6—Safety Injection System Failure Modes and Effects Analysis
Sheet 10 of 10

Component	Component Function	Failure Mode	Failure Mechanism	Failure Symptoms/ Effects	Can SIS/RHRS Satisfy Mission Success Criteria?
Safety-Chilled Water System Main Components QKA	Provide cooling for the LHSI pumps Trains 1 and 4 (motor cooler and sealing medium)	a) Failure to operate	Mechanical/Electrical/ I&C	Loss of cooling for the mentioned components.	Yes, as it only affects one train.
SB Controlled-Area Ventilation (KLC) System Recirculation Cooling Unit 30KLC51 AC001 30KLC52 AC001 30KLC53 AC001 30KLC54 AC001	Provide cooling to the SIS/RHRS rooms within the SB	a) Failure to cool	Mechanical/Electrical/ I&C	Potential overheating of LHSI and MHSI pumps.	Yes, as it only affects one train.

Next File